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ABSTRACT

A long-term study was conducted to test the effectiveness of visual thinking networking (VTN), a new generation of knowledge representation strategies with 56 ninth grade earth science students. The recent findings about the brain's organization and processing conceptually ground VTN as a new cognitive tool used by learners when making their knowledge explicit. VTN encourages students to integrate multiple ways of thinking about scientific events and objects by utilizing color, form, and spatial information. These attributes have been recently linked to the understanding of how one builds a picture of the visual world, stores this new knowledge and recalls it in our brain. This paper presents an overview of findings from an experimental and interview-based design. The use color promoted long-term meaningful learning and achievement, and enhanced the higher order thinking skills of problem solving. A summary of the five major positive findings are presented in the areas of problem solving achievement, organization of knowledge in memory, problem solving strategy dimensionality, conceptual understanding, and gender differences. Issues of assessment and curriculum planning, and the role of the senses in concept formation are also addressed. Appended are: constructed networks, concepts used in the first VTN and Writing Strategy Topic: Earth and Space Science, and Guidelines for Constructing a Visual Thinking Network. (Contains 34 references, 7 figures, and 1 table.) (Author/YDS)

What happens to student learning when color is added to a new knowledge representation strategy?

Implications from Visual Thinking Networking[1]

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[1] The symbolic representation and visual thinking networks appearing in this paper were created in color. A full color text of this paper can be found by clicking on my name at www.umassd.edu/cas/biology

Abstract for ERIC Database

What Happens to Student Learning when Color is Added to a New Knowledge Representation Strategy?

Implications form Visual Thinking Networking

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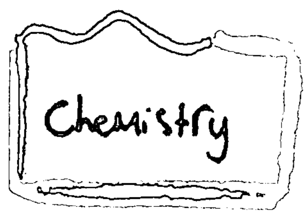
Abstract: A long-term study was conducted to test the effectiveness of visual thinking networking (VTN), a new generation of knowledge representation strategies with 56 ninth grade earth science students. The recent findings about the brain's organization and processing conceptually ground VTN as a new cognitive tool used by learners when making their knowledge explicit. VTN encourages students to integrate multiple ways of thinking about scientific events and objects by utilizing color, form, and spatial information. These attributes have been recently linked to the understanding of how one builds a picture of the visual world, stores this new knowledge and recalls it in our brain. This paper presents an overview of findings from an experimental and interview-based design. The use color promoted long-term meaningful learning and achievement, and enhanced the higher order thinking skills of problem solving. A summary of the five major positive findings are presented in the areas of problem solving achievement, organization of knowledge in memory, problem solving strategy dimensionality, conceptual understanding, and gender differences. Issues of assessment and curriculum planning, and the role of the senses in concept formation are also addressed. Contains 34 references.

Target Audience: Students, Teachers, Teacher Education Practitioiners

Descriptors: Visual Thinking Networks; Knowledge Representation Strategies; Metacognitive Learning Strategies; Neurocognitive Science; Earth Science Problem Solving Achievement; Color Encoding and Knowledge Reconstruction; Gender Differences in Science Learning

One of the most important agendas put forth by the current science education reform movement is that "teachers need strategies to help students learn meaningfully" (Glynn & Duit, 1995, p. 199).



> I chose these colors because they were opposites. You know, a lot of chemistry involves different things. I used this shape to show that chemistry is made up of, unpredictable reactions... a lot of reactions can be spontaneous and some can be totally predicted....The curvy part would be disorder, and the straight lines, you just represent the more predictable part of chemistry (Pilot study interview, 1995).

These statements were from Peter, a high school chemistry student, as he explained how he constructed a visual thinking network on chemical kinetics (Appendix A).

As a teacher/researcher, I developed and implemented a metacognitive learning strategy, called visual thinking networking in my science teaching practice. Visual thinking networking (VTN) is a new generation of knowledge representation strategies conceptualized from current neurocognitive science. Students use VTNs for organizing their science knowledge by constructing network diagrams using semantic and figural elements to represent knowledge relationships. As a metacognitive learning strategy, VTN "empower the learner to take care of her/his own learning in a highly meaningful

fashion" (Novak, 1998a, p.1). The term "visual thinking" is derived from the work of Rudolf Arnheim (1969). For Arnheim "the perception of shape marks the beginning of concept formation" (p. 27). VTN then, is a tool for a learner to organize, represent, and revise her/his meaning making of science knowledge by chunking and linking conceptual labels with colored symbolic visualizations of scientific concepts, processes, and experiences into a coherent whole. The planning, organizing, the making of the chunks and the connections are undirected by the teacher and becomes an aspect that is most crucially idiosyncratic and imaginative (Appendix B).

This strategy was recently tested in a long term, ten month study (Longo, 2001). The findings from this year-long study **indicate that thinking visually in color promotes long-term meaningful learning and problem solving achievement especially for female students.**

Neurcognitive Science Conceptually Grounds Visually Thinking Networking

In order to answer the focus question of this paper, "What happens to student learning when color is added to a new knowledge representation strategy"?, it is important to establish the conceptual framework, the theory that frames or grounds this strategy. VTN is a new knowledge representation and metacognitive learning strategy because when students organize and represent their science knowledge they are employing the same categorizing strategies that our brain uses when perceiving an event in our external world. They are using the attributes of color, form, location, and verb-noun mediation when constructing their earth science knowledge. These attributes have been recently linked to the understanding of how one builds a picture of the visual world, stores this new knowledge, and recalls it in our brain (Zeki, 1984, 1988, 1990a, 1991,

1992, 1993a; Damasio, 1990, 1992, 1993, 1994; Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; Ungerleider, 1995).

Neurocognitive science is a new and highly interdisciplinary field of study that bridges the concepts and methods from three main disciplines, neuroscience, experimental psychology, and computer science (Gazzaniga, 1995, 2000; Kosslyn & Andersen, 1992). Neurocognitive science provides new methods and conceptual frameworks for linking neural systems to cognitive events (Posner & Raichle, 1994). In doing so, neurocognitive science as a discipline seeks to identify the biological or neural substrates that correlate to cognition (Eimas, 1990). Researchers explain how these correlates are involved in the processes of attention, perception, and memory. These processes in turn mediate brain functions such as reasoning and language.

Anderson (1991, 1992, 1997) has explicitly paved an important path in science education, linking the empirical and theoretical findings from neurobiology and neurocognitive science to a constructivist view of learning. One of the major insights gained from Anderson rests in the plausibility of the multi-modal (visual, auditory, kinesthetic) cortical maps that are established during sensory input "may be the neurophysiological correlates to the extended associational networks known as schemata in cognitive science" (1992, p. 1043). The role of the multi-modal learning tasks and strategies become important tools both in the learner's acquisition, representation, and assessment of knowledge.

Four important findings from neurocognitive science provide us with new information on the organization and processing in the human brain. It is from the perspective of these findings that VTN as a metacognitive learning and knowledge

representation strategy is conceptually derived.

- Knowledge is distributed into anatomically separate regions of the brain. Early visual processing categorizes our visual world into constructs of color, form, location, and motion.
- The organization of the visual cortex is a distributed network of neural ensembles in which perception and cognition occurs simultaneously.
- Elaborate feedforward and feedback connections are established. As a result the early visual categorizations have diverse functional roles in the cognitive processing related to memory, attention, and thinking visually.
- Reconstruction of knowledge from memory (recall) involves the reactivation of the original sense representation that were formed when the perceiver was sensing an object or an event.

To better understand these findings in relation to science classroom instruction let's look at the following earth science learning scenario: *A sunny day. Students are out in the field collecting evidence of earth's rotation by marking the changes that occur in the position of a shadow casted by a pencil like pole during a forty-minute time period. Groups of three students are assembled on the ground in front of a shadow board (a one square foot piece of wood one inch thick, with a hole in the center of the board).*
One student places a sheet of white paper on the board, another places a pencil in the center. They are instructed to observe and draw the pencil's shadow every five minutes for forty minutes. Ten minutes pass and one student says, "the path of the pencil's

shadow is changing." Ten minutes later another student makes a similar observation. Students continue to trace the shadow of the pencil every five minutes.

The next day in class, students discuss and analyze the data. Although the students experience and memory of this phenomena is a unitary event, herein lies the "paradox of vision" (Zeki, 1993, p. 295). The picture that is emerging from studying the visual cortex is one that shows a deep division of labor. The different attributes of both the objects involved in collecting data and the events of what occurred, such as the color, shape, motion, and location are processed, stored and reconstructed during memory from anatomically separate parts of the brain (Zeki, 1988, 1993; Martin *et al.*, 1995; Ungerleider, 1995).

Let us return to the earth science classroom, but one week after the students collected and analyzed the shadow board data. *As an assessment, each student is asked to write what happened as they collected data and to explain why. The memory of the field experience, using the shadow board and collecting data can evoke the original visual and tactile representations of the color, shape, depth, motion, and location, even the path that the hand and arm took to trace the shadow of the pencil. All these representations are re-created in separate brain regions, but their reconstruction occusr simultaneously as one memory event..*

The role of the senses is involved in concept formation since perception and cognition are now viewed as a continuous and co-extensive process. What is critical for classroom experiences is to have a diverse number of multi-modal (auditory, visual, and tactile) learning tasks for the acquisition, representation, and assessment of knowledge. These multi-modal experiences will then continue to strengthen the internal connections between the distributed forms of knowledge. Perhaps assessment then can be view as authentic with respect to the modality in which the learning experience occurred.

Testing Visual Thinking Networking in the Classroom

What happens to student learning when color is added to a Visual Thinking Network? The findings from an experimental (pre-post control group) and interview-based study indicated the importance of using color in VTN strategies. **The use of color promoted:**

1. **the encoding (formation) and reconstruction (recall) of earth science knowledge from memory.**
2. **the improvement of the higher order thinking skill of problem solving in both a paper-pencil knowledge achievement test and in an interview, think-out-loud problem solving experience.**
   - Females moved up this problem solving achievement ladder with respect to a paper pencil test in relation to their male counterparts.
   - Females expressed their scientific knowledge more relationally than males during the think-out-loud problem solving experience.

(3) long-term meaningful learning.

The Study

A ten month study was conducted in a natural classroom setting with fifty six 9th grade earth science students (13-15 years of age) to test the effectiveness of VTN as a science learning strategy (Longo, 2001). Thirty-four students were females (n=34) and twenty-two (n=22) were males. The site was a small suburban high school outside of NYC. Students were randomized into three classes: two experimental (VTN) and one control group(writing strategy). VTNs were used as a metacognitive learning tool for

representing earth science knowledge acquired throughout the academic year. At the conclusion of three major units of study (earth in space, the atmosphere, solid earth and earth's history), both the experimental and control groups were given the same set of earth science concepts that characterized each unit (Appendix C). The VTN or experimental group had the choice of constructing VTNs in color or black/white, with or without symbolic images. These students were given no instruction in how to think visually with respect to earth science objects or events. They were however, given guidelines as how to construct a VTN (Appendix D). The writing strategy or control group were given instructions on how to use a variety of writing strategies, such as fictional writing or prose to express their understanding of the same set of earth science concepts.

An overview of the major findings are presented from the perspective of the two designs that sought to answer the particular research questions. Graphic plots from this study are provided to support these findings.

Overview of Findings from the Experimental Design

Is earth science learning improved as a result of students choosing and using VTNs for learning science? The experimental design sought to establish relationships between achievement and the use of VTN learning strategies by looking for gains on an earth science knowledge test before (pre) and after (post) students were using the VTN strategies for learning earth science.

The findings from the experimental design indicated that there is a causal relationship between problem solving achievement and using VTN strategies for learning science:

- Earth science learning was improved in the area of problem solving achievement for those students who used VTNs (color and black/white).
- Earth science learning was most improved in the area of problem solving achievement for those students who used color VTNs **(see Figure 1, p. 20)**.
- Earth science learning was most improved in the area of problem solving achievement for students with high abstract reasoning aptitude who used the color VTNs.
- Color VTN strategies helped both male and female students in problem solving achievement. The gender achievement gap was shortened for females who used the color VTN strategies. **(see Figure 1, p. 20)**.
- Gender influenced the choice of a VTN strategy. Females used more color VTN strategies than males.

The findings from the experimental design significantly established a causal relationship. Earth science learning, in the area of problem solving achievement, was significantly improved for those students who used VTN strategies for learning science ($p = .005$). Although significance was found what does this mean in terms of classroom practice? Table 1.0 below summarizes the percentage gain in problem solving achievement in terms of possible score on the problem solving area of the AGI/NSTA Earth Science Exam (Callister, *et al.* 1988). The experimental group had a twenty-six 26%) achievement gain while the control group had a twelve percent (12%) gain. This doubling effect indicates how strong the significant effect was.

Closer examination of Table 1.0 summarizes the percentage achievement gain in problem solving with respect to groups who used different strategies for learning science. The percentage gain was the highest (30%) for those students who used the color VTN strategies for learning science.

Table 1.0

Percentage Gain in Problem Solving Achievement

Group	**Percentage Gain** $= \frac{\text{mean gain}}{\text{total score}}$	**Male**	**Female**
Experimental	$\frac{4.143}{16}$ = 26%	$\frac{4.813}{16}$ = 30%	$\frac{3.579}{16}$ = 22%
Control	$\frac{1.810}{16}$ = 11%	$\frac{1.667}{16}$ = 10%	$\frac{1.867}{16}$ = 12%
Strategy Group	**% Gain**	**Male**	**Female**
Color VTN	$\frac{4.8}{16}$ = 30%	$\frac{6.6}{16}$ = 41%	$\frac{4.0}{16}$ = 25%
B/W VTN	$\frac{2.5}{16}$ = 16%	$\frac{3.0}{16}$ = 19%	$\frac{1.3}{16}$ = 8%
Writing	$\frac{1.8}{16}$ = 11%	$\frac{1.7}{16}$ = 11%	$\frac{1.9}{16}$ = 12%

Overview of the Findings from the Interview-Based Design

Students were asked to solve a problem about an event involving time, planetary motion, and seasons, by thinking out loud eight months after they received instruction on this content material. The interview-based design explored what aspects of student's thinking were influenced by the utilization of VTN strategies.

Five major positive findings emerged from this design of the inquiry in the area of organization of knowledge in memory, problems solving strategy dimensionality, conceptual understanding, and gender differences.

Organization of Knowledge in Memory

- The earth science knowledge recalled during a think-out-loud problem solving interview by students who used color VTN strategies, was significantly more interrelated than the earth science knowledge recalled by those students who used the writing strategies. This means as the color VTN students were adding new information to solve the interview problem they continually went back and revisited previously stated concepts, thus making more connections **(Figure 2, p. 21).**

Problem Solving Dimensionality

- Students who used the color VTN strategies significantly generated more knowledge during the think-out-loud problem solving interview than students who used the black/white and writing strategies **(Figure 3, p. 22)**.

- Students who used the color VTN strategies significantly used a greater number of knowledge action verbs and different kinds of knowledge action verbs to describe planetary events and objects during the think-out-loud problem solving interview than students who used the writing strategy **(Figure 4,5, p. 23-24).**

Conceptual Understanding

Students of low abstract reasoning aptitude who used the color VTN strategies for learning science:

- generated more accurate conceptions about time, planetary motion, and seasons than students who used black/white VTN and writing strategies during the think-out-loud problem solving interview **(Figure 6, p. 25).**
- generated more accurate conceptions in the form of symbolic representations about time, planetary motion, and seasons than students who used the black/white VTN and writing strategies during the think-out-loud problem solving interview **(Figure 7, p. 26).**

Gender Differences (Figure 2-3 p. 21-22).

- The earth science knowledge recalled by female students during a think-out loud problem solving interview was significantly more interrelated than the earth science knowledge recalled by male students.
- The earth science knowledge recalled during the think-out-loud problem solving interview by female students who used the color VTN strategy for learning science was significantly more interrelated than the earth science knowledge recalled by male students in the black/white and writing strategy.

- Females significantly generated more earth science knowledge during a think-out-loud problem solving interview than males.

Two unexpected results emerged from the interview-based design. First, not only was female earth science knowledge significantly more interrelated than male knowledge, but as females used the color VTNs for learning science, their knowledge became more interrelated. These female color VTN students were able to generate more accurate connections in their ability to solve problems.

What type of student benefits from constructing color VTN strategies for learning earth science? The findings from interview-based design establish an interrelationship between learners of high and low abstract reasoning aptitude who are metacognitively engaged in the construction of color VTNs to specific positive changes in their knowledge base as identified in Figure 8. These changes influenced their long-term meaningful learning and achievement in the cognitive domain of earth science problem solving.

Two levels of cognitive processing occurred for those students who constructed the color VTNs for learning science. First, on a more fundamental level, the use of color in the VTN acted as an attentional device for discriminating or categorizing knowledge. Second on a deeper more complex, or higher level of processing, color coding acted as a mechanism to reactivate large numbers of distributed neural networks. The important and common element between these two levels is that they are both involved in enhancing conceptual recall and in the reconstruction of memory. At the fundamental level, the more attributes one uses to code scientific events and objects the more likely they can be

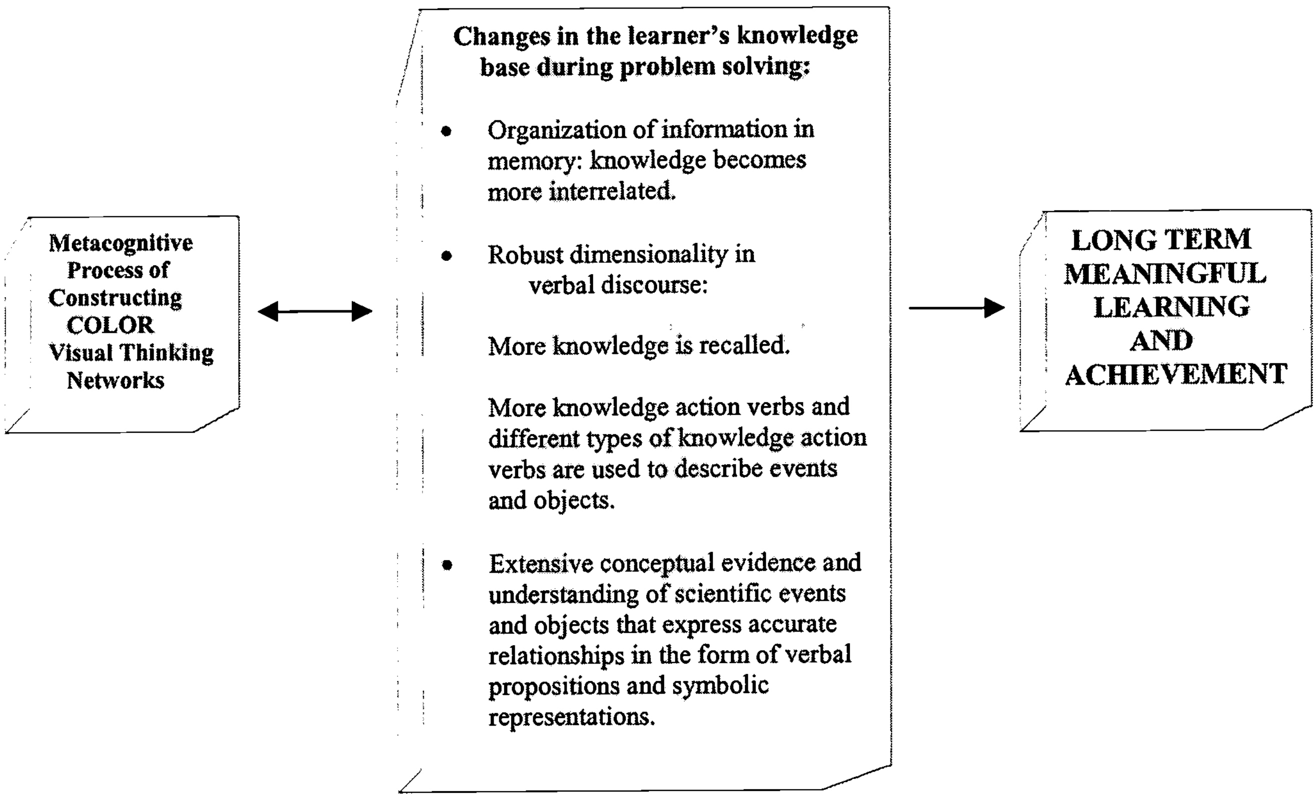


Figure 8. Positive changes in the learner's knowledge base during problem solving resulted in long term meaningful learning and achievement. The double arrow headed line between the learner and the positive changes in their knowledge base indicates that there may be some dynamic(s) within the learner that enables he/she to elaborate these constructions by using color in the VTNs.

reconstructed. The richness in the number of color attributes used in the VTNs to codify phenomena was elaborated during the interview-based design.

When the experimental group was asked to explain why they make certain meaningful depiction decisions, such as the use of color and images, during the construction of the VTNs students said (the number inside the bracket refers a different student number code):

> Colors are definitely helping me out in thinking, remembering, and associating each color [2].... The color gives it clarity in each section, it helps me [9].....Color helps me read it better and things stand out more [14]... Color attracts my attention more. I always use color in other school projects. By using color, it is a way of organizing myself. I use certain colors for certain areas [19]...Color makes it easier to decipher [23]....I made each group a different color [23].... The color groups things into categories and I can understand how everything connects [25]....Colors were used to distinguish between certain categories [27].....I choose colors to group things [33].. Using color, definitely was important [38].

A new metacognitive learning theory, the encoding activation theory of the anterior cingulate (ENACT-AC), has been proposed by this author to explain the findings from this long term study in the context of neurocognitive science (Longo, 2001).

The Process, the Product, and Assessment

One of the most important changing emphasis found in the National Science Education Standards (1996) is with respect to the notion of student understanding. According to the Standards, "understanding science requires that an individual integrate a complex structure of many types of knowledge, including the ideas of science, relationships between ideas, reasons for these relationships" (p. 23, 1996). The specific

Assessment Standards calls for placing "more emphasis on assessing scientific understanding and reasoning, and assess what students do understand", (p. 100, 1996).

Using a knowledge representation strategy like Visual Thinking Networking for learning science can help the teacher address three important questions with respect to assessment:

- **How do we know that they know?**
- **What does their knowledge look like?**
- **How is their knowledge changing throughout instruction?**

From my experience of using VTN for science learning <u>the process</u> of constructing/building different knowledge relationships is just as important as the final product, the visual thinking network. The VTN becomes an indispensable tool for classroom discourse, talking. This discourse can have many different forms, such as having a student explain and or justify to a small group of peers the reasons they used types of connections/relationships in building a network. Often it is easier for students to do this with a one-on-one peer or in a small group. The ability to talk about one's explanations and justifications for knowledge relationship becomes vital towards achieving scientific literacy. In my classroom practice I would use "help sessions" whereby I could listen to the reasons as to why students would make certain connections and relationships between different types of science knowledge. This dialogue is very valuable to students by helping them to identify their alternative scientific conceptions. By doing so, they can go back to the VTN and revise their understanding to accommodate and integrate new and accurate scientific knowledge. Without this aspect of integration of old or prior knowledge to new incoming knowledge, the new knowledge

will not re-organize and assimilate as part of the learner's learning schema. The VTN helps the learner to metacognitively attend to this process of integration.

Resnick said, " to understand something is to know relationships" (p. 477, 1983). By carefully looking at the construction or validity of the links, that is the direction of the relationship of the arrow expressing the relationship and the choice of the linking verb chosen to express the relationship between two or more concept nodes in a network, a teacher tell if they understand the relationship between concepts.

This linking characteristic of a VTN is shared with other knowledge representation strategies such as concept mapping (Novak, 1990, 1998) and semantic networking (Fisher, 1995). Mason (1992) has developed an excellent scoring rubric for concept mapping that can be adapted to evaluate a VTN. (Appendix E).

Closure to this aspect of assessment brings to mind one last question for the science classroom teacher to ask: *What changes in my thinking of and planning for assessment needs to take place so can have students use VTNs effectively?* Creating just the time and space in one's curriculum for the use of VTN may not be enough. What role or value to you place upon the physical and metacognitive construction of knowledge? What role or value do you place upon having small student centered conversations either between you and the learners or between a small group of learners about the process of constructing or building scientific knowledge? Answers to these questions may shape and or re-shape one's philosophy about teaching and learning science with respect to the role of the teacher, the learner, and the curriculum. This change may then inform one's practice, that is the way science looks like in the classroom by becoming a very active and particpartory way of knowing.

Summary

Two very broad issues are brought to bear on the implications for using color VTNs for learning science. First, the findings derived from this research provide us with a new understanding of knowledge building. Second, we are compelled to look at the ways females express their thinking.

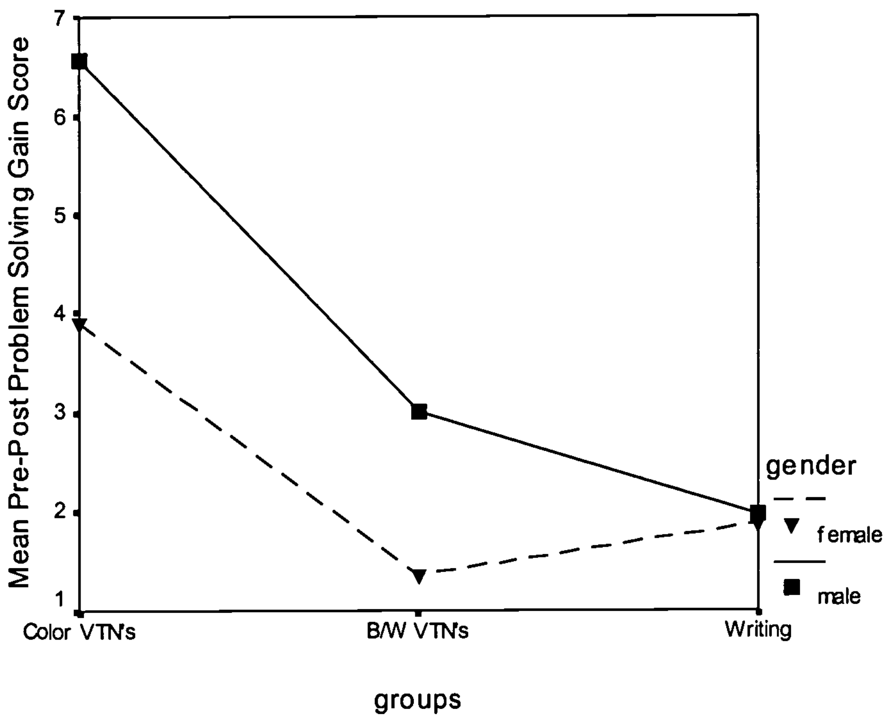
Lemke (1998) argued for the "teaching of all the languages of science: words, symbols, images, and actions" (p. 1). Multiple ways of thinking about science concept formation allows for the transformation in the forms we encourage students to use in order to represent what they have come to know (Eisner, 1994). Meaning making has been described as "fundamental adaptation of the human species and the driving force underlying all forms of conceptual change" (Mintzes, 1999, p. 1). The color attributes used in the construction of the VTNs are not added for artistic reasons alone, rather they provide another dimension in decision making, reflective and conceptual thinking as the learners make their knowledge explicit in a highly meaningful and idiosyncratic manner. Based on the findings as presented in this paper, it is especially important that female students be given the access to a variety materials and tools so they can represent and build their science knowledge meaningfully using the relational aspects of color. Since females students significantly chose to use construct more VTNs in color than males, it is important to continue to encourage males to pick up the colored pencils/markers when building their science knowledge base.

In The National Science Standards (1996) the National Research Council has called for the integration of theory to practice by the promotion of a "minds on" (p. 20) approach to learning science. To this end, the development of higher order thinking skills and the need to teach thinking skills has become a major driving force in the current science educational reform movement. The findings in this paper indicate that the higher order thinking skill of problem solving is improved for male and female students as a result of using color VTN strategies for learning science.

Visual thinking networking strategies encourage learners to choose meaningful color and symbolic visualizations for as a vehicle to bring together their experience of the scientific concepts and processes into a coherent whole. By doing so, we encourage a broadened view of color as knowledge in the brain. This view supports Eisner's arguments for "a transformation of the ways in which we teach, the curriculum resources we employ, and the form we allow students to use in order to represent what they have come to know" (1994a, p. 87).

With respect to the gender differences as indicated in this research, what does the presence of a relational mode of thinking about science knowledge mean in terms of classroom practices? This relational way of thinking about the world needs to be acknowledged, given spaces in our classrooms so that it can be seen and heard. Educators must pause, reflect upon, and re-evaluate methods of assessment. If science educators are not looking for or measuring relational thinking then the tools for which we assess learning and achievement are not valid for females. More exploration is needed to understand this dynamic way of thinking about the world.

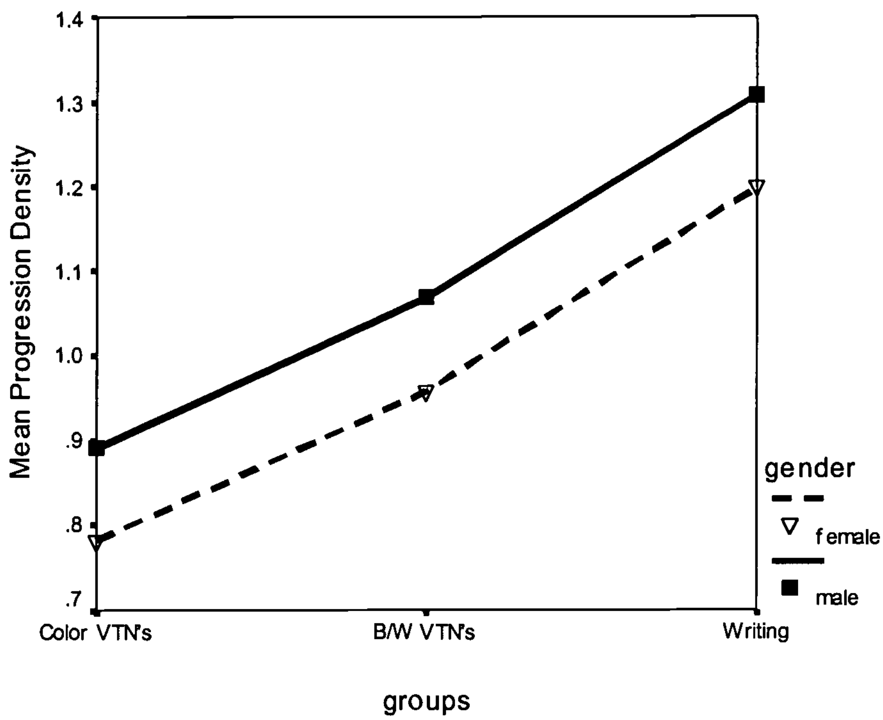
Figure 1. **Comparison of pre-post Problem Solving Mean Achievement Gain Score between students who used different strategies for learning science**[2]



Significant Pairwise Comparisons	
Color VTN – B/W VTN group	**p = .003**
Color VTN – Writing Strategy	**p < .001**

[2] Earth science learning was most improved in the area of problem solving for those students who used the color VTN strategies. The post test was administered nine months after the pre test. The gender problem solving achievement gap was shortened for the females who used the color VTN strategies for learning science.

Figure 2. **Comparison of a Knowledge Inter-relatedness coefficient in a think-out-loud problem solving interview between students who used different strategies for learning science**[3]

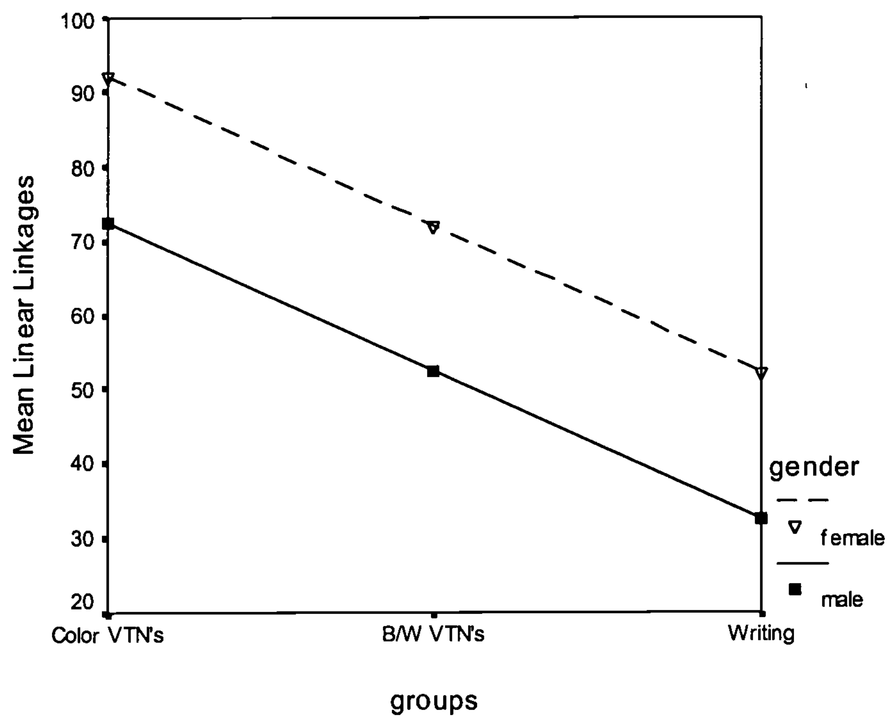


Significant Pair-Wise Group Differences	
Color VTN - B/W VTN Group	$p = .050$
Color VTN - Writing Group	$p < .001$

Significant Pair-Wise Gender Differences	
Male – Female	$p = .043$

[3] A lower knowledge inter-relatedness coefficient (progression density) indicates less progressive elaboration of ideas in a think-out-problem solving interview (given eight months after instruction) and more recursive and cross-related thought. Students who used color VTN strategies generated more inter-related knowledge than other groups. Female earth science knowledge is more inter-related than male earth science knowledge.

Figure 3. **Comparison of the Amount of Knowledge Generated in a think-out-loud problem solving interview between students who used different strategies for learning science**[4]



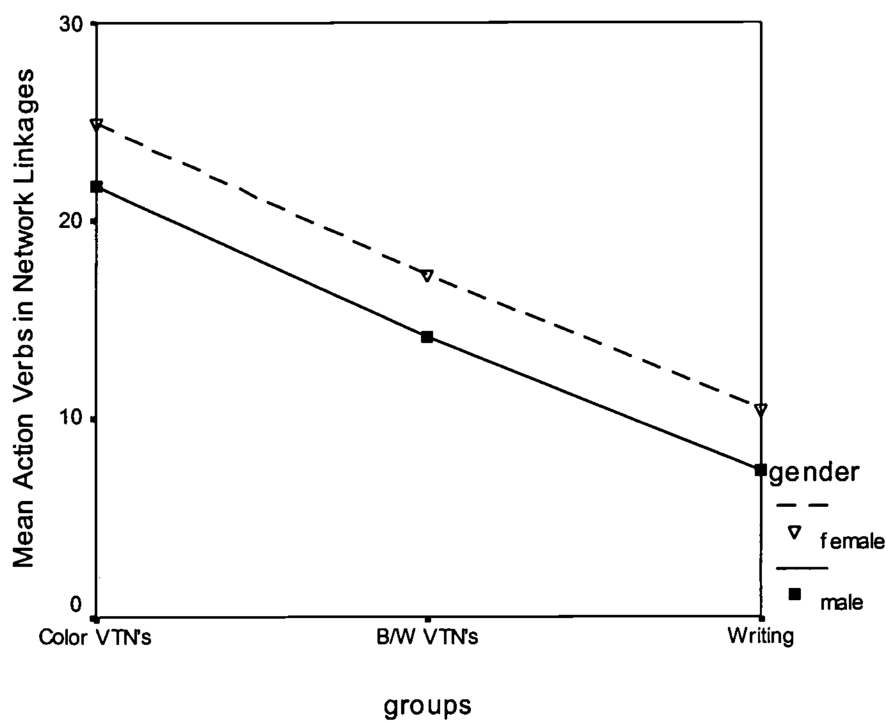
Significant Pair-Wise Group Differences	
Color VTN - B/W VTN Group	$p = .021$
Color VTN - Writing Group	$p < .001$

Significant Pair-Wise Gender Differences	
Female-Male Group	$p = .010$

4 Students who used the color VTN strategies generated more earth science knowledge (number of linear linkages) during the think-out-loud problem solving interview that occurred eight months after instruction than the two other groups. Females generated more earth science knowledge than males.

Figure 4.

Comparison of the mean number of knowledge action verbs generated in a think-out-loud problem solving interview between groups who used different strategies for learning science[5]

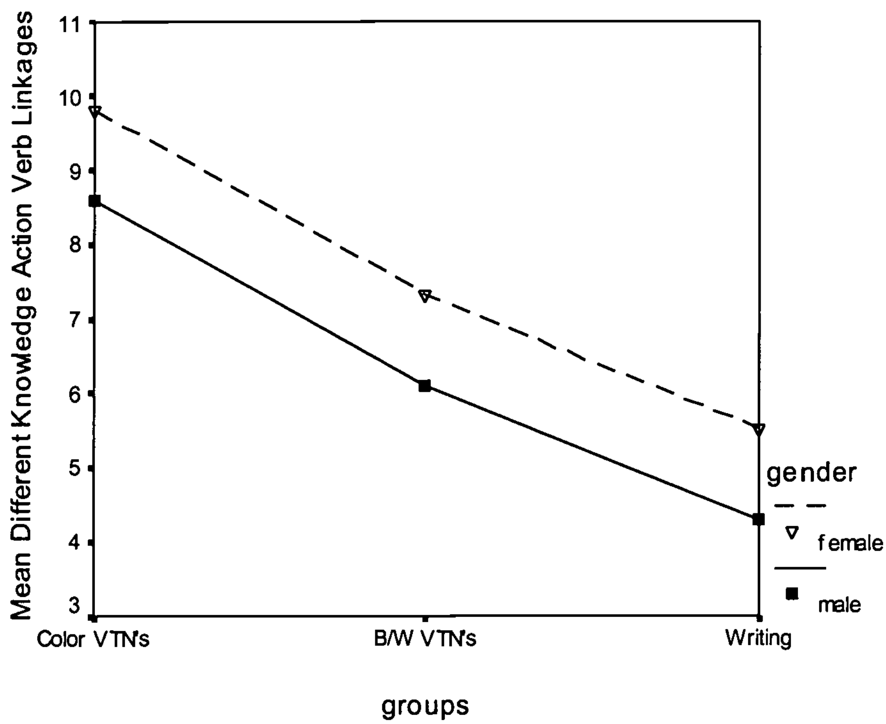


Significant Pairwise Comparisons
color VTN –writing group p = .006

[5] Students who used the color VTN strategies generated more knowledge action verbs (rotate, revolve, swing, move, etc.) during a think-out-loud problem solving interview that occurred eight months after instruction than students who used the writing strategy.

Figure 5.

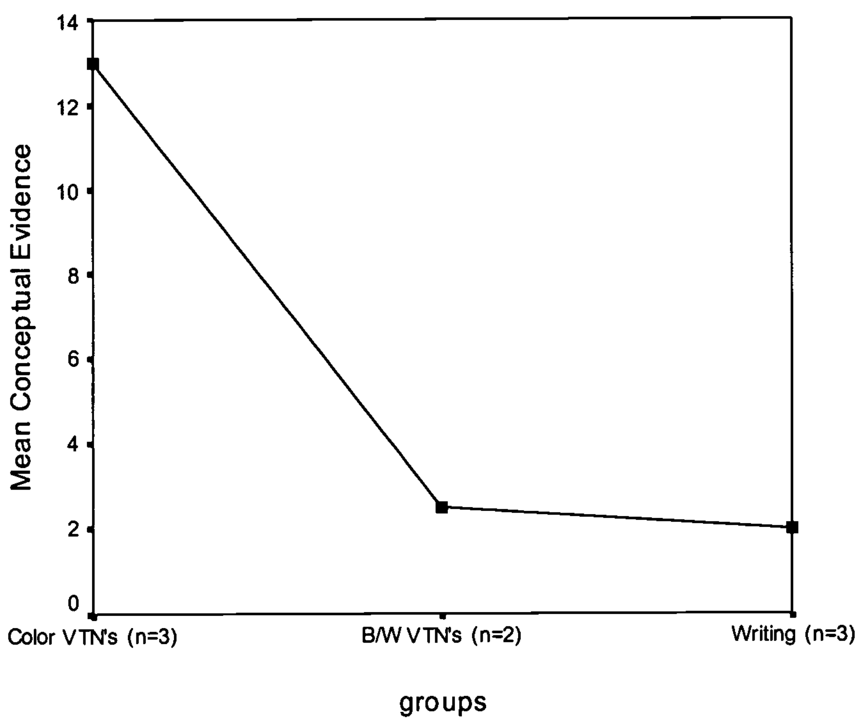
Comparison of the mean number of different kinds of knowledge action verbs generated during a think-out-loud problem solving interview between groups who used different strategies for learning science[6]



Significant pairwise comparisons **color VTN – writing strategy p = . 033**

[6] Students who used the color VTN strategies generated more kinds of different types knowledge action verbs (rotate, revolve, swing, move, etc.) during a think-out-loud problem solving interview that occurred eight months after instruction than students who used the writing strategy.

Figure 6. **Comparison of Conceptual Evidence about Time, Planetary Motion, and Seasons between groups of students with low abstract reasoning aptitude who used different strategies for learning**[7]



Significant Differences Between Groups

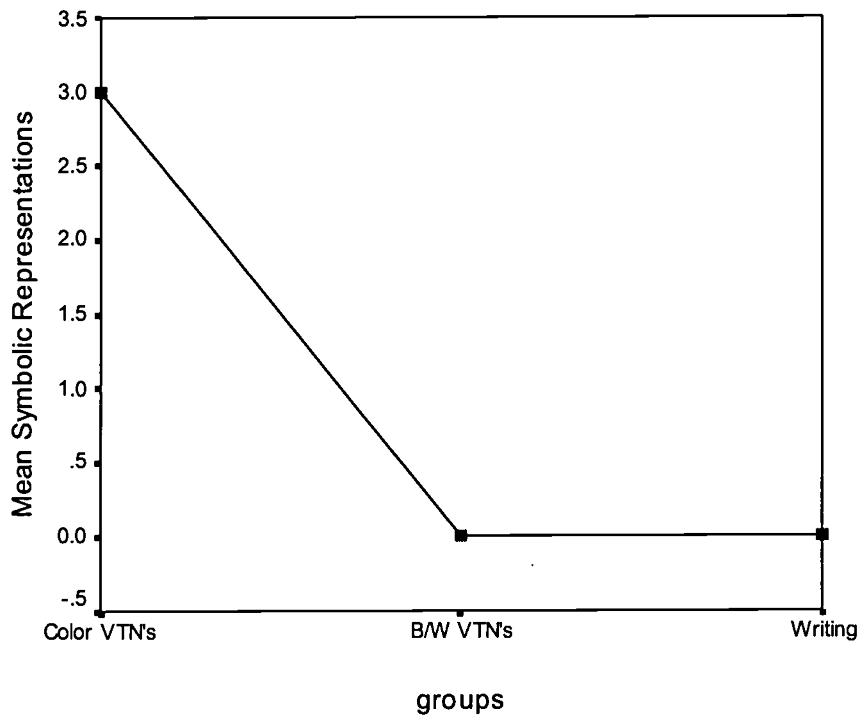
Color VTN - B/W VTN Group p = .018

Color VTN - Writing Group p = .010

[7] Low abstract reasoning aptitude students who used the color VTN strategies generated more conceptually accurate knowledge during a think-out-loud problem solving interview that occurred eight months after instruction than students who used other strategies.

Figure 7.

Comparison of Conceptual Evidence in the form of Symbolic Representations about Time, Planetary Motion, and Seasons between groups of students with low abstract reasoning aptitude who used different strategies for learning[8]



Significant Differences Between Groups	
Color VTN - B/W VTN Group	p = .048
Color VTN - Writing Group	p = .034

[8] Low abstract reasoning aptitude students who used the color VTN strategies generated more conceptually accurate knowledge in the form of symbolic representations during a think-out-loud problem solving interview that occurred eight months after instruction than students who used other strategies.

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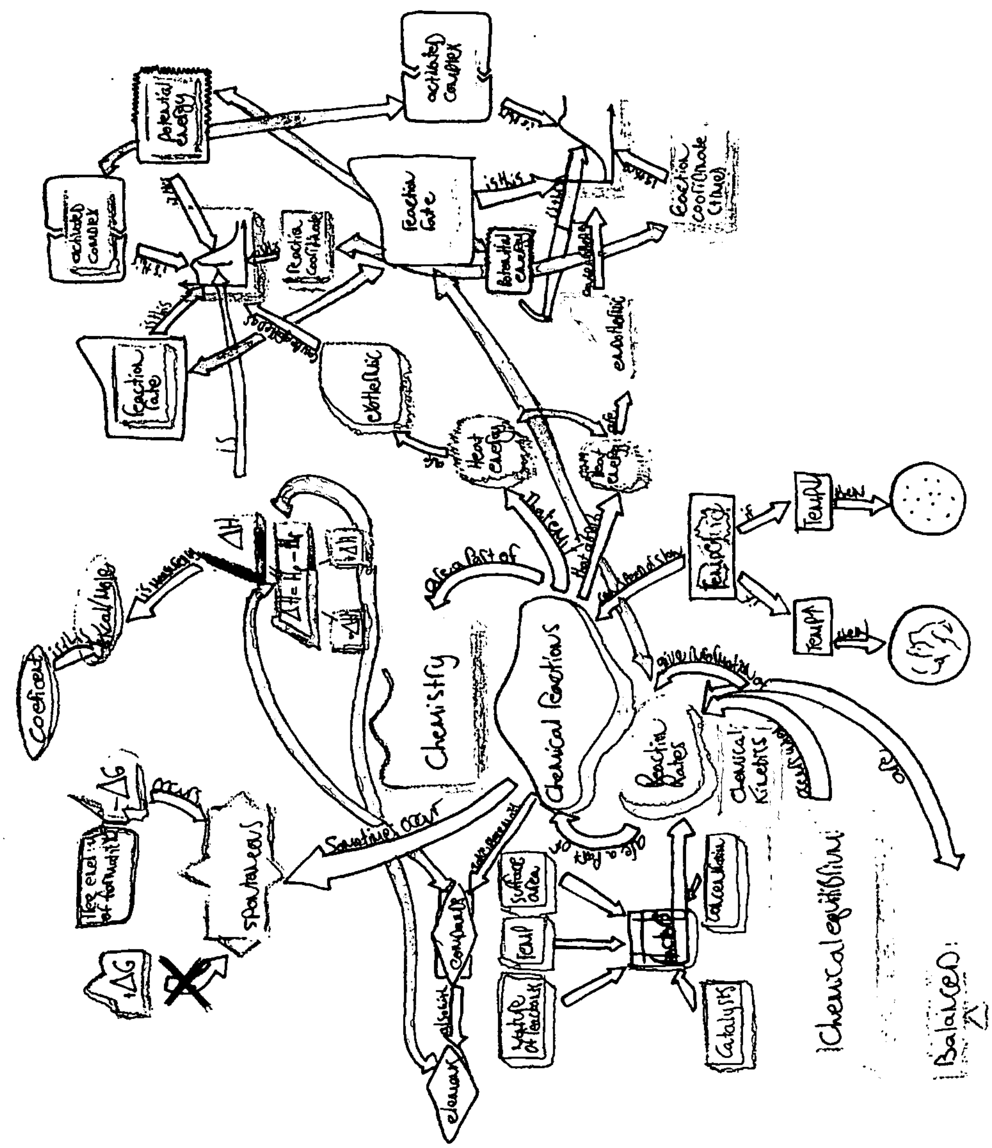
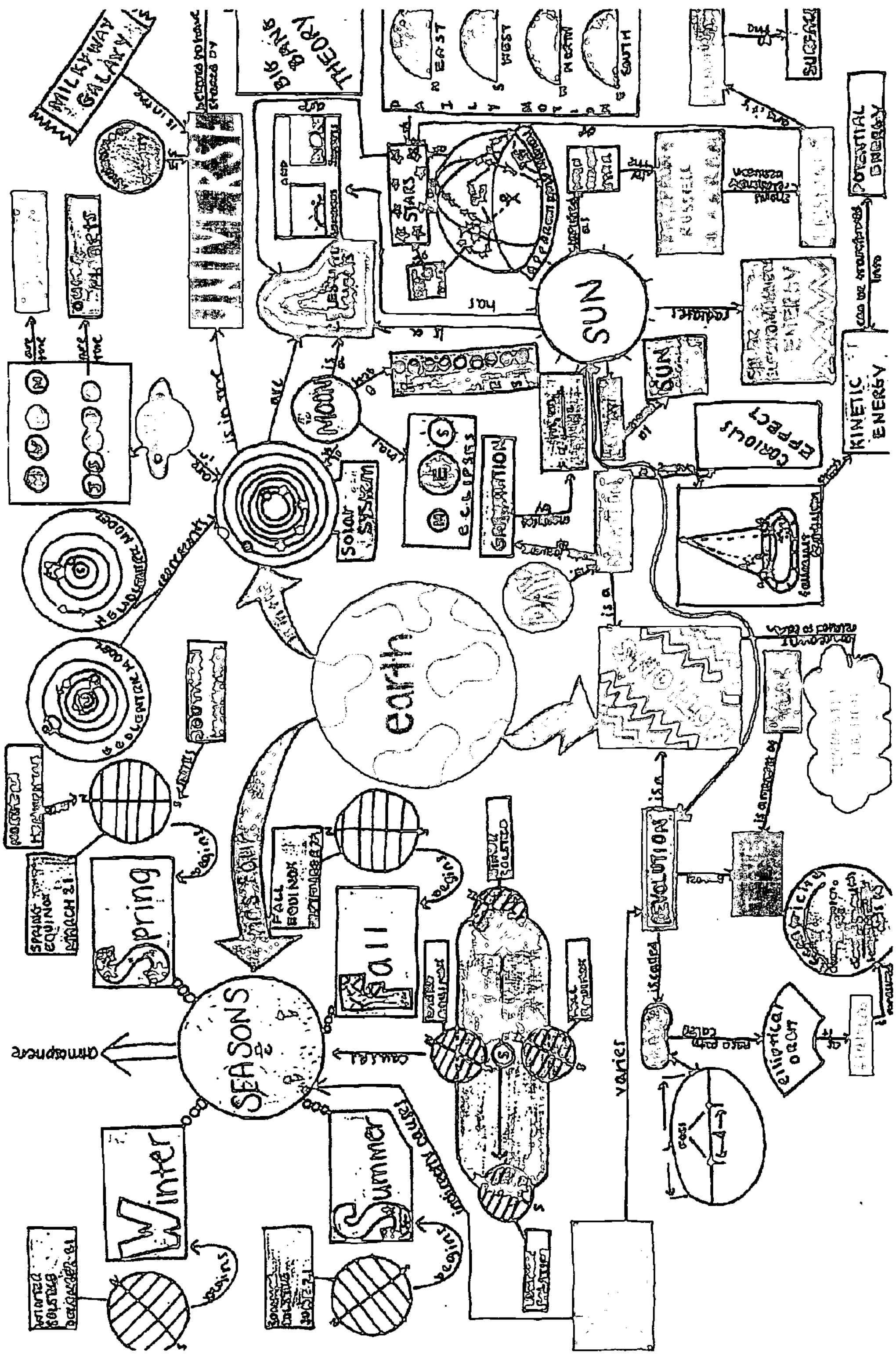
Appendix A: Peter's network on chemical kinetics



Appendix B. Network constructed by a female earth science student



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Appendix C.

Concepts used in the first VTN and writing strategy Topic: Earth & Space Science

earth	summer	Big Bang theory	inner planets
sun	moon	day	star
motion	fall	spring	winter
time	rotation	winter solstice	summer solstice
stars	suntracker	apparent motion	spring equinox
eclipse	revolution	terrestrial motion	elliptical orbit
latitude	rotation	Hertzprung-Russsell	Doppler effect
axis	velocity	planet period	focus (of an ellipse)
sunrise	sunset	23.5 degree tilt	outer planets
Polaris	planets	parallelism of earth's axis	gravitation
eccentricity	moon	N & S hemisphere	Coriolis effect
tides	seasons	Foucault pendulum	shadow length
universe	solar energy	angle's of sun altitude	moon phases
	fall equinox	kinetic energy	surface temperature
		length of daylight	heliocentric model
		potential energy	geocentric model
		solar system	main sequence

Appendix D

Guidelines for Constructing A Visual Thinking Network

A visual thinking network (VTN) is a vehicle or strategy for **meaningful learning** whereby you describe your understanding of a particular topic by integrating multiple ways that inform your knowledge building.

Characteristics of a Good VTN

VTNs are an individual's representation of knowledge, one's meaning making. VTNs are unique or idiosyncratic, that is people can construct different VTNs on the same topic. A network is created by connecting or linking one concept label to to another. Here are some general characteristics to well-constructed VTNs.

1. A VTN is created around one focal or centering point. This focal point need not be "centered" in the middle of the page. The placement is up to you and what meaning you are constructing with it's placement in the VTN. As you work with on building your science knowledge may see that your focal point changes to a different concept.

2. Main branches may emerge from the centering point that describe main ideas about a science topic. Sub-branches can then be created from these main branches.

3. The unit of knowledge construction is the concept node or label. These concept labels are usually nouns, a single idea about different scientific objects and or events. Concept labels may be enclosed with a characterizing shape or form.

4. Each concept label is connected to another concept label. This relationship is formed by placing linking words on the top of an arrow-headed line. These linking words are usually verb, verb phrases, adverbs, prepositions, or prepositional phrases. Each concept label appears only once in the VTN.

5. The direction of the arrow from one concept to another describes the nature of the relationship you are expressing.

6. The structure of the link can be used to express different relationships between concept labels. There are four types of linking structures: such hierarchy, chain, cluster, and recursive. Page 27-28, in these guidelines will help you understand these four structural relationships between concepts.

7. **The use of color is highly encouraged when constructing your VTN. It has been proven that adding color helps facilitate the encoding and recall of knowledge into memory.** Color may be used to distinguish different levels of concepts or ideas you are trying to express.

8. The use of symbolic representations, images, or metaphors are encouraged to show the multiple ways of expressing concept formation.

9. Crosslinks are used to show relationships between concepts in different parts of the network. Crosslinks are created in a particular color to distinguish them from arrowheaded linking lines. Cross links are bi-directional arrows.

Constructing your VTN

1. Be patient.... this is a new strategy you are learning how to use. One in which you are being asked to think about thinking. That is why VTN is also called a metacognitive learning strategy because you are thinking about your thinking. There is no "right" way to construct a VTN. Remember this network will show your understanding of a body of scientific knowledge.

2. Materials you needs:
   - set of blank concept labels cut-outs
   - 11 x 17 paper
   - black pen and colored pencils

3. Generate or brainstorm a list of concepts that your classnotes, textbook readings, laboratory activities, and class demonstrations. Place these concepts on smaller pieces of paper (cut-outs of concept labels) so you can move them around on the large piece of paper.

Look at all your concept labels and ask yourself the following questions

- Do any of these concept labels act as a focal point?
- What type of relationships can you express with these concept labels?

5. One way to begin to is to group related concepts. These groups of concepts share a similar relationship. As you are moving these concept labels around ask yourself:

   - *what is the criteria, the decision, that was made for a concept label to be a member of this group?*

   Write down this criteria. This criteria may become and other concept label.

6. *What type of network link (hierarchy, chain, cluster, or recursive) can you use to express the nature of the relationship between these grouped concepts?*

7. Networking is a process and you may develop several "working VTNs" until you have the one that expresses your understanding of the concepts in the topic. For example you may choose one concept label as the focal point of your first VTN draft then change to a different focal point as you begin working through the nature of the relationships you want to express. (SEE EXAMPLES)

8. *Can you identify one focal point?* Place this concept label on your large piece of paper and enclose it with some shape and color.

9. *What concepts do you want to branch from this point?*

10a. *What relationship do you want to express connect the focal point to the main branches?* Write the linking word on the top of the arrow-headed line.

   b. *What is the direction of the relationship? What concept is the arrowhead line pointing to?*

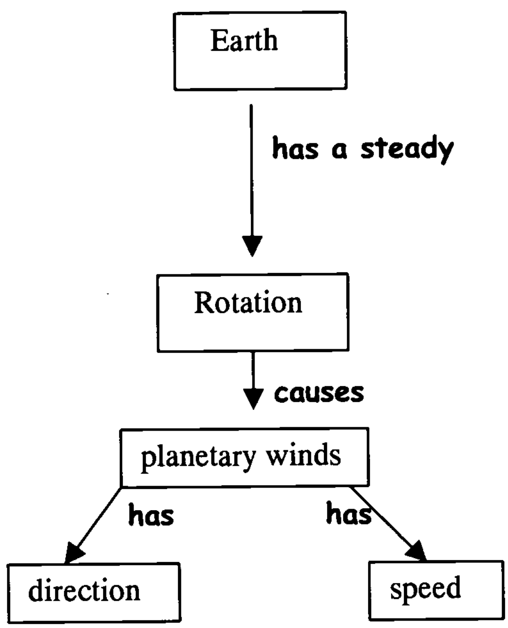
10. Continue to link all the concept labels you generated in your brainstorming session.

11. When finished ask yourself..

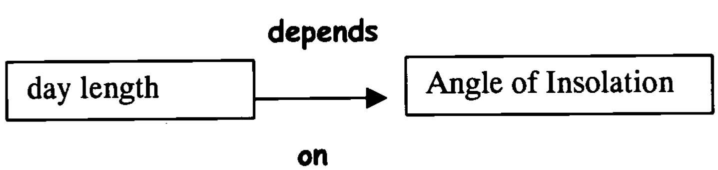
   - Does this VTN show my understanding of a body of scientific knowledge?
   - How scientifically accurate or valid are the connections, the links between each concept?
   - Have I used a variety of links to express different relationships between concepts.

Four Types of Structural Links:

1. Hierarchy



2. Chain



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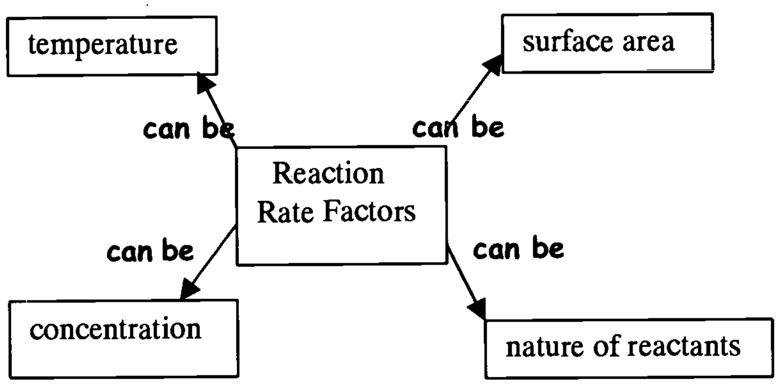
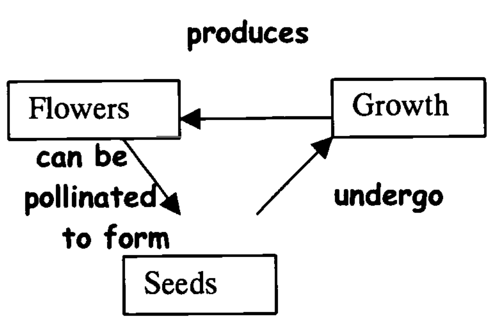
3. Cluster



4. Recursive or cycle like



Appendix E

Mason's Scoring Rubric Developed for Concept Mapping Can Be Used with Visual Thinking Networks

Criteria	**Levels of Adherence***				
	Poor 1	**Fair 2**	**Good 3**	**Very Good 4**	**Excellent 5**
Number of Concepts					
Focal Concepts					
Validity of Linkages					
Number of Linkages					
Horizontal vs. Vertical Flow					
Semantic Categories of Links					

*** Basis for determine the level of adherence**

Number of Concepts: tends to have too few or too many concepts vs. only the major concepts.
Focal Concepts: misses the major foci vs. hierarchically indicates the major foci.
Validity of Linkages: formed proposition is inaccurate vs. formed proposition is accurate.
Number of Linkages: leaves our numerous possible linkages vs. includes important linkages.
Horizontal vs.Vertical Flow: tends to extend in one direction vs. fairly even.
Semantic Categories of Links: propositional links are vague or missing vs. explicit.

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